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TLD MEASUREMENTS OF GAMMA HEATING IN HEAVY ELEMENTS

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ABSTRACT

Measurements and calculations of gamma heating in polyethylene and lead containers were done and compared. The objective was to provide a workable method of getting good values for gamma heating in in-pile experiments containing materials of high atomic numbers. It was inferred that a combination of thermoluminescent dosimeter measurements, using Bragg-Gray theory, with photon transport calculations using the ANISN computer program, would meet this objective.

INTRODUCTION

In a previous work[1] we showed results of calorimeter measurements of gamma-induced heating in platelet specimens of various atomic numbers and thicknesses. That work gave some useable data. But, as we remarked in that work, further effort is still required on a case basis to get good numbers for configurations containing arbitrary geometries and materials. The purpose of this paper is to show some things we did with lithium fluoride thermoluminescent dosimeters (TLD's) and computer calculations to try to demonstrate a workable method of getting good gamma heating values, thus facilitating design and analysis of in-pile experiments.

EXPERIMENT DETAILS

Figure 1 shows three small cylindrical containers, each of which contained three TLD discs and three TLD rods mounted on the vertical centerline. The rods were 0.635 cm L x 0.076 cm D; the discs were 0.635 cm D x 0.0127 cm T. Two of the containers were lead, 5 cm H x 2.5 cm OD x 0.3 cm wall. The other was polyethylene, which we take to be equivalent to water in regard to gamma-ray transport. One of the lead containers was voided; the other two containers were water-filled.

Two sets of these three containers were mounted on a "flux-wheel" and placed next to the Plum Brook Mock-Up Reactor, as shown in Fig. 2. The wheel rotated during irradiation so that each container received the same dose.

A statistical analysis was done on the resulting data (Fig. 3). Effects of axial position of the TLD's in the containers and effects of replication -- that is, set 1 or set 2 -- were determined to be insignificant. The resulting treatment means are shown on Fig. 3. Also shown are bars which underline those means which are not significantly different from each other at an α-treatment level of 0.10.

Normalizing all the response values to the "water only" case (the polyethylene bottle), we see in Fig. 3 that introduction of the lead container around the detectors reduced their response by 22 percent. When that lead container was then voided, the discs increased by 115 percent while the rods increased 35 percent.

We corrected the disc response values (for the voided case) according to Bragg-Grey theory. We used Pg. 190 and Pg. 387 of "Radiation Dosimetry" by Attix and Roesch[2]. This gave a value of 1.53 for the ratio, (electron mass stopping power of water) divided by (electron mass stopping power of lead), for the .0127 cm discs. Dividing the disc response values by 1.53, we get a value of 1.1 for R, which is defined to be the ratio of gamma heating in lead, in W/g, to that in water at the same location when the lead is not present. This is interpreted as being proportional to the gamma heating at the inside wall of the voided lead container.

CALCULATIONS

Then we did computer calculations of the photon flux and gamma heating in the same geometry. We used the ANISN program[3], very like we did in correlating our previous work[1]. We did calculations in slab, cylindrical and spherical geometry.

Figure 4 shows the geometry for the slab calculations.

Figure 5 shows the calculated gamma heating, with and without the lead, for slab geometry. It shows that the introduction of the lead reduces the gamma heating in water at the container centerline by 30 percent. The gamma heating at the inner wall in lead is about 28 percent greater than in water before the lead is present.

The calculations for cylindrical and spherical geometry gave smaller values for both these numbers, in better agreement with the measurements. We show the slab geometry result here because it shows the attenuation across the entire diameter of the container.

A calculation of the gamma heating within a voided lead container showed a negligible effect of the void.

DISCUSSION

We thus observe that calculations and measurements agree that introduction of the lead decreases the gamma heating at container centerline by about 25 percent. We infer that the dosimeters correctly measure the gamma heating in water in the cavity when enough water is present to make the electron spectrum at the dosimeters roughly an equilibrium spectrum for water. Here "enough water" is less than 1 cm; how much less, we don't know at this time.

When the container is voided the TLD rods and discs both give a greatly enhanced response even though the calculations indicate the true gamma heating does not increase. We were able to use textbook data from Bragg-Gray theory to correct the 0.0127 cm disc responses to give realistic values for lead; we were not able to do this for the 0.076 cm diameter TLD rods. We infer that TLD discs of 0.0127 cm thickness can be used to get good values using Bragg-Gray theory; how much greater thicknesses could be used, we don't know at this time. (In fact, lesser thicknesses should improve accuracy because the correction for thickness decreases with lesser thicknesses.)

OTHER RELATED WORK

Another measurement recently made by us had a 0.025 cm thick lead plate with a 0.0025 cm thick TLD inside, in water, as shown in Fig. 6. The same geometry was also calculated by ANISN. The results are also shown. The calculations and measurements agree the gamma heating in lead is about six times as great as in water when the lead is absent. This result indicates that a container material could be quite thin (<0.025 cm lead) and still give roughly an equilibrium spectrum in a cavity.

We conclude from all this that a combination of ANISN calculations and TLD measurements can be used to obtain adequate design values for in-pile experiment configurations containing some heavy element materials. We are now using these methods at Plum Brook.

Another trick we have used with success is to surround the "sensitive" portion of an in-pile experiment with a heavy element shield. Then we assume that a TLD rod response can be used directly. For example, one experiment contained columbium internals and was entirely gamma-heated.

A columbium gamma shield was placed around the experiment. The heating measurements were made with 0.076 cm diameter TLD rods and used directly, without recourse to Bragg-Gray theory or computer calculations. The experiment ran within 10 percent of its design point of 1273 K, which we think is outstandingly good considering no thermal mockup was ever made.

CONCLUSIONS

The conclusions suggested by this work are shown in Fig. 7. Additional measurements with TLD's are planned to give further support to these conclusions and to define limits of their applicability. The results will be reported later.

REFERENCES

1. H. J. REILLY and L. E. PETERS, JR., "Calorimetric Determination of Relative Gamma Heating in Materials of Various Thicknesses and Atomic Numbers," Nuc. Tech., 11, 89-95 (May 1971).

2. F. H. ATTIX and W. C. ROESCH, Radiation Dosimetry, Academic Press, Vol. I, 2nd Ed., (1968).

3. W. W. ENGLE, JR., "A Users Manual for ANISN: A One-Dimensional Discrete Ordinates Transport Code with Anistropic Scattering," K-1693, Union Carbide Corp., (1967).

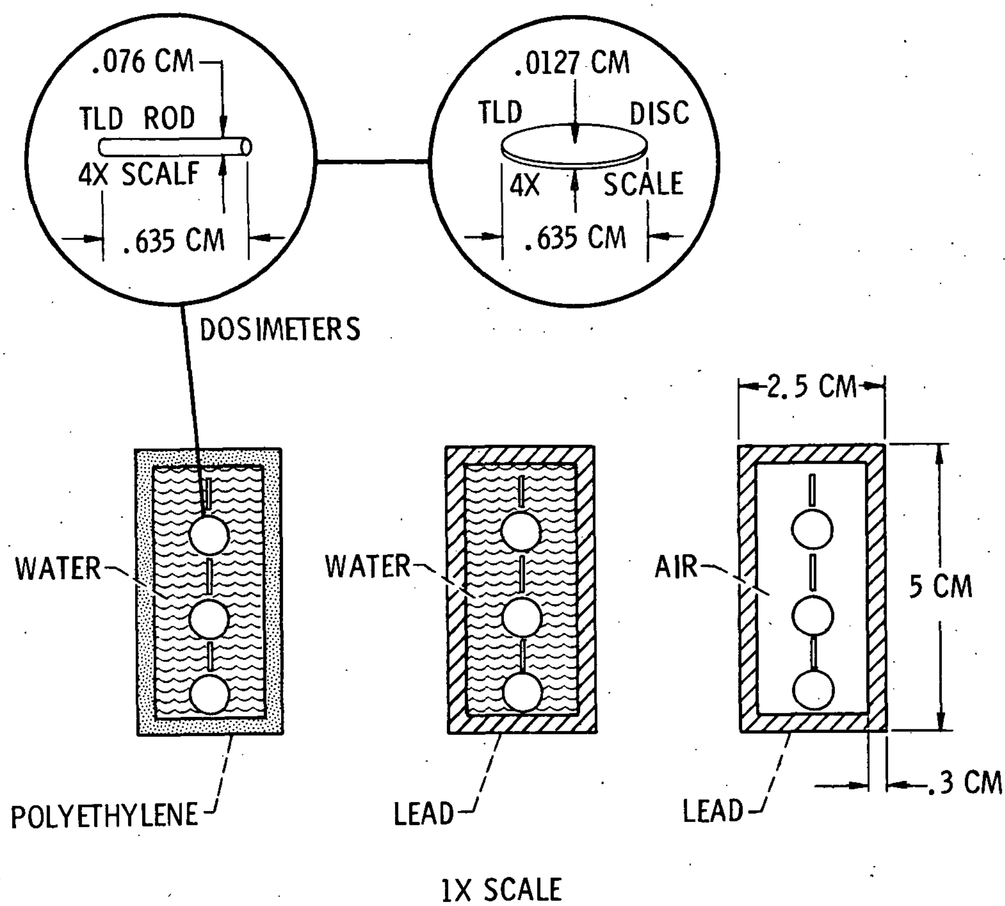

Figure 1. - Containers used in irradiation experiment.

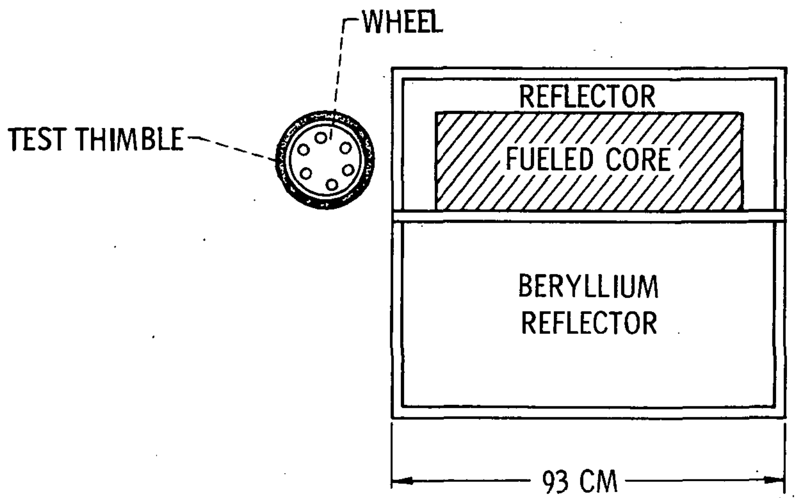

Figure 2. - Plan view of mockup reactor with experiment on "flux wheel."

		RAW DATA					
		LEAD				POLYETHYLENE	
		WATER		AIR		WATER	
		1ST SET	2ND SET	1ST SET	2ND SET	1ST SET	2ND SET
TLD RODS	TOP	268	205	320	335	281	293
	CENTER	213	221	349	308	296	271
	BOTTOM	225	234	301	231	325	290
TLD DISCS	TOP	210	217	477	466	259	319
	CENTER	224	207	389	523	309	244
	BOTTOM	221	208	469	448	262	277

S = 34.8

	AVERAGED DATA		
	LEAD		POLYETHYLENE
	WATER	AIR	WATER
TLD RODS	228.0	307.7	293.0
TLD DISCS	215.0	462.3	278.7

MEANS IN ASCENDING ORDER: 215.0 228.0 278.7 293.0 307.7 462.3

NORMALIZED AVERAGED DATA		
.80	1.08	1.03
.75	1.62*	.97
.78	1.35	1.00 (BY DEFINITION)

$^*\dfrac{1.62}{0.97} \div 1.53 = 1.1$ BY BRAGG-GREY THEORY.

Figure 3. - List of data and data averages.

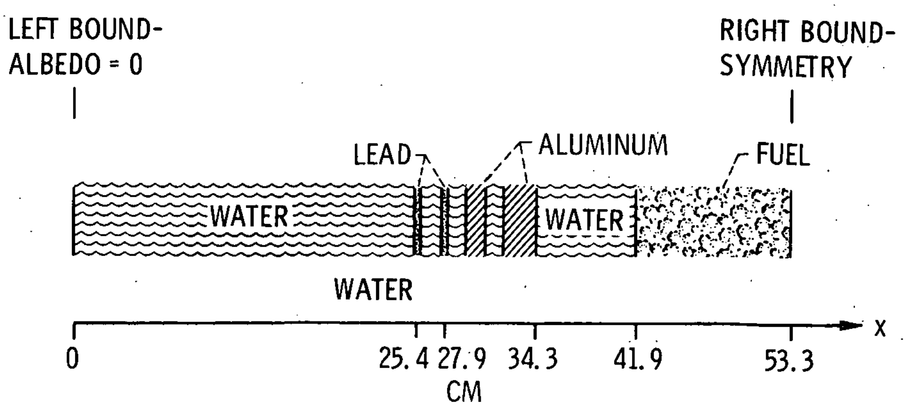

Figure 4. - Slab calculation geometry.

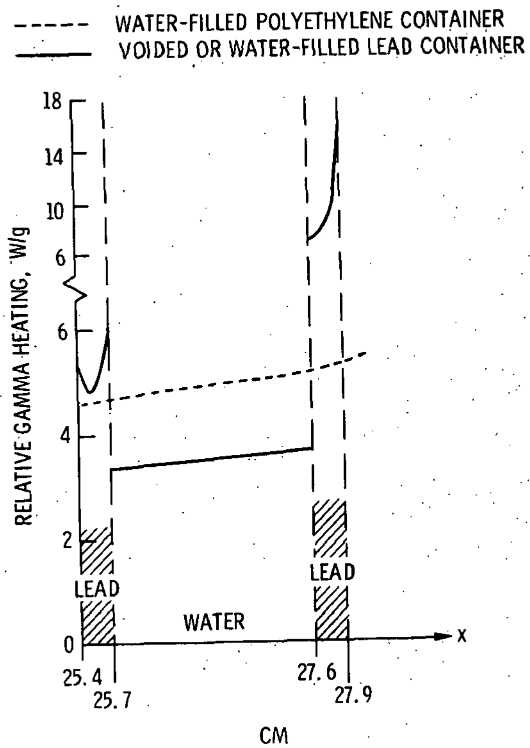

Figure 5. - Calculated gamma heating in container and contents, lead or polythylene container material, geometry of figure 4.

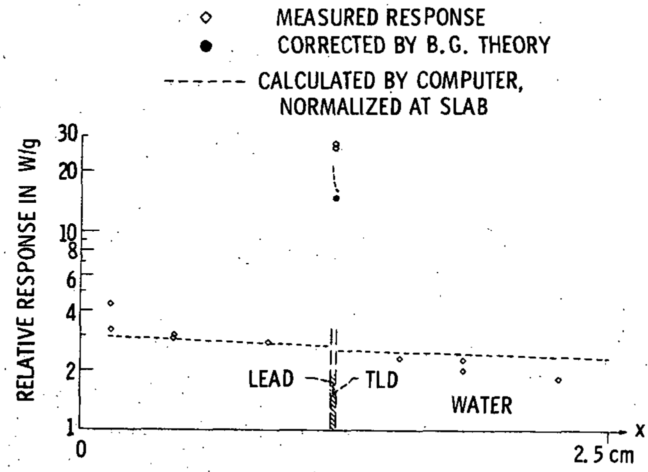

Figure 6. - Calculations and measurements of 0.025 cm lead slab containing 0.0025 cm.

THESE OBSERVATIONS SUGGEST THE FOLLOWING CONCLUSIONS:

1. LiF TLD'S CAN BE USED TO MEASURE THE GAMMA-HEATING IN WATER IN A CAVITY INSIDE A CONTAINER IF THE CAVITY CONTAINS SUFFICIENT AQUEOUS MATERIAL TO SCREEN OUT THE LOW ENERGY ELECTRONS ENTERING THE CAVITY FROM THE CONTAINER.

2. LiF TLD'S CAN BE USED TO MEASURE THE GAMMA-HEATING IN CONTAINER MATERIAL IN A VOIDED CAVITY USING BRAGG-GRAY THEORY IF THE TLD IS SUFFICIENTLY THIN.

3. EITHER MEASURED VALUE CAN BE USED TO NORMALIZE CALCULATED VALUES FROM THE ANISN PROGRAM TO OBTAIN GAMMA-HEATING VALUES AS A FUNCTION OF POSITION IN THE CONTAINER.

Figure 7. - List of conclusions.